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CONSTRUCTION OF A FORMAL METHODOLOGY TO REFINE A SPARES SUITE USING TIGER

by

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This thesis proposes a method for setting inventory levels for a suite of spares for a ship subsystem. The method extends the one proposed by Judge and Leutjen [Ref. 1] which uses a computer simulation model called TIGER to modify the levels of shipboard spare parts determinted by a sparing model. By combining TIGER and the Availability Centered Inventory Model (ACIM), one of the coordinated shipboard allowance list (COSAL) models currently used in the U.S. Navy, our method is able to achieve the same level of operational availability for ship systems at less cost.

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Construction Of A Formal Methodology To Refine A Spares Suite Using TIGER

by

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ABSTRACT

This thesis proposes a method for setting inventory levels for a suite of spares for a ship subsystem. The method extends the one proposed by Judge and Leutjen [Ref. 1] which uses the TIGER computer simulation model to modify levels of shipboard spare parts that have been determined by a sparing model. By combining TIGER and the Availability Centered Inventory Model (ACIM), a coordinated shipboard allowance list (COSAL) model currently used in the U.S. Navy, our method is able to achieve the same level of operational availability, as that of ACIM alone, for ship subsystems at less cost.

TABLE OF CONTENTS

I. INTRODUCTION 1

A. HISTORICAL BACKGROUND 1

B. PROBLEM DESCRIPTION 3

C. THESIS OBJECTIVE AND SCOPE 5

II. ACIM METHODOLOGY 8

A. MODEL INTRODUCTION 8

B. ALGORITHM DESCRIPTION 10

C. MODEL SHORTCOMINGS 17

D. SUMMARY 18

III. TIGER SIMULATION...................................19

A. MODEL INTRODUCTION 19

B. CURRENT USAGE 19

C. ALGORITHM DESCRIPTION 22

D. TIGER OUTPUTS 23

E. SUMMARY 25

IV. SPARING METHODOLOGY 27

A. HYPOTHESIS 27

B. MEASURES OF EFFECTIVENESS 27

C. METHODOLOGY 28

V. GPS-5 RECEIVER SYSTEM 34

A. SYSTEM CHARACTERISTICS 34

B. SYSTEM CONFIGURATION 34

VI. CONCLUSIONS AND RECOMMENDATIONS 34

A. SIMULATION RESULTS 36

B. CONCLUSIONS 42

C. FUTURE STUDIES 43

APPENDIX A. AVAILABILITY CONCEPTS 44

APPENDIX B. THE NAVY INVENTORY SYSTEM 47

APPENDIX C. CURRENT SPARING MODELS 51

APPENDIX D. GPS-5 SYSTEM PARAMETERS 56

APPENDIX E. GPS-5 SYSTEM CONFIGURATION....................57

APPENDIX F. ACIM STOCK LEVELS FOR GPS-5 SYSTEM 58

APPENDIX G. FLSIP AND MOD-FLSIP STOCK LEVELS 59

APPENDIX H. ACIM STOCK LEVEL ADJUSTMENTS (PHASE 1) 60

APPENDIX I. ACIM STOCK LEVEL ADJUSTMENTS (PHASE 2) 61

LIST OF REFERENCES 62

INITIAL DISTRIBUTION LIST 63

LIST OF FIGURES

Figure 1. ACIM Marginal Analysis Technique 11

Figure 2. TIGER Run Diagram 20

Figure 3. Reliability Block Diagram 21

Figure 4. TIGER Program Flow Diagram 24

Figure 5. Sparing Methodology Flow Diagram 33

Figure 6. Current Sparing Cost Comparison 37

Figure 7. TIGER Simulation Results, Rule 1 40

Figure 8. TIGER Simulation Results, Rule 2 41

Figure 9. U.S. Navy's Three Echelon Inventory Structure..................................48

Figure 10. Poisson Distribution of Demand 52

LIST OF SYMBOLS, ACRONYMS AND ABBREVIATIONS

A_o	- Operational availability defined as the probability that an item will be capable of performing its specified function when called for at any random point in time
A_{om}	- Average Mission Operational Availability
ACIM	- Availability Centered Inventory Model
CDU	- Control Display Unit
COSAL	- Coordinated Shipboard Allowance List
DC	- Duty Cycle
DOD	- Department of Defense
FLSIP	- Fleet Logistics Support Improvement Program Model
FRPA-3	- GPS-5 Antenna Assembly
GPS-5	- Global Positioning System Radio Receiver
ICP	- Inventory Control Point
MLDT	- Mean Logistics Delay Time (a measure of supply support posture)
MOD-FLSIP	- Modified FLSIP Model
MOE	- Measure of Effectiveness
MSRT	- Mean Supply Response Time, synonymous with MLDT
MTBF	- Mean Time Between Failure (a measure of reliability)
MTTR	- Mean Time To Repair (a measure of maintainability)
NAVSEA	- Naval Sea Systems Command
NAVSUP	- Naval Supply Systems Command
NSC / NSD	- Naval Supply Center / Naval Supply Depot (overseas)

RBD	- Reliability Block Diagram
RMA	- Reliability, Maintainability and Availability
RPU	- Receiver Processor Unit
SPCC	- Ship's Parts Control Center
TIGER	- Monte Carlo computer simulation model used in RMA analysis
TRF	- Technical Replacement Factor

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I hold myself solely responsible for any errors or deficiencies in this thesis. I gratefully share any credit, that this thesis may receive, with all who contributed to its completion.

I. INTRODUCTION

A. HISTORICAL BACKGROUND

During the past ten years, the Navy has conducted several studies to evaluate and compare existing and new sparing models which are used to manage the Navy's material inventories. In the early inventory models, the Navy simply modified those which existed in industry to meet its goal; namely, to maximize effectiveness given a certain budget constraint. For a long time, system and supply effectiveness took on many related but different forms. Consequently, the methods used to achieve those effectiveness goals were often not uniformly understood. In addition, it is not clear that improved supply effectiveness necessarily leads to improved system effectiveness. It was inevitable that a measure of effectiveness for material readiness needed to be formalized throughout the Navy. NAVMATINST 3000.2 [Ref. 2] states that operational availability, denoted as A_o, "is the primary measure of material readiness for Navy weapons systems and equipment." In this instruction, A_o is defined as "the expected percentage of time that a weapon system or individual equipment will be ready to perform satisfactorily in an operating environment."

In 1981, a model called the Availability Centered Inventory Model, ACIM, was recommended and approved for use by the Navy in a single echelon environment. The estimate for operational availability used within ACIM is the ratio of the length of time a system is available and the length of a mission (or the length of time the system must be operationally available). In short,

$$\begin{aligned}\hat{A}_o &= \text{UPTIME / TOTAL TIME}\\ &= \text{UPTIME / (UPTIME + DOWNTIME)}\end{aligned}$$

Another estimate for A_o which is widely used in the literature and in Department of Defense applications is the following (see, e.g., Ref. 3):

$$\hat{A}_o = \text{M}\hat{\text{T}}\text{BF / (M}\hat{\text{T}}\text{BF + M}\hat{\text{T}}\text{TR)}$$

where MTBF is the estimated mean time between failure and MTTR is the estimated mean time to repair given there is no waiting time for the repair to begin. However, such an assumption is inappropriate in the Navy, and the following estimate of A_o is used in ACIM instead:

$$\hat{A}_o = \text{M}\hat{\text{T}}\text{BF / (M}\hat{\text{T}}\text{BF + M}\hat{\text{T}}\text{TR + M}\hat{\text{L}}\text{DT)} \tag{1}$$

where MLDT is the estimated mean logistics delay time. (MLDT is also referred to as estimated mean supply response time, MSRT.)

B. PROBLEM DESCRIPTION

The U.S. Navy currently provides spare suites for ship systems using several methods and coordinated shipboard allowance list (COSAL) models. One of the methods employed develops a set of spares for each individual system by selecting the range and number of each spare (depth) which will maximize the system's estimated operational availability given a budget constraint. One such optimization model, ACIM, is utilized to build spare suites for use at the unit level. There are inherent problems in the ACIM model which prevent it from selecting the optimal range and depth of spares at minimal cost while relating the selected spares to the intended system mission.

ACIM, while it links $\hat{A}_0$ with COSAL, does not consider the operational mission or mission cycles which the component will experience while in use. As further stated in NAVMATINST 3000.2, "...$\hat{A}_0$ does not depict the ability of the system or equipment to continue to perform satisfactorily for the duration of a specific mission cycle. That particular issue is 'dependability' or 'mission availability'...." Although the procedure of using $\hat{A}_0$ for determining the correct mix and quantity of spares to an operational unit is a step in the right direction, the better measure of effectiveness is a combination of $\hat{A}_0$ and the probability of "mission success". Ideally, the suite of spares that is positioned at an operational unit should provide a sufficiently high probability that a required system will be operational when called upon and should be related to the intended operational mission of the system. Additionally, the spares suite provided should be one of minimal cost.

Although the U.S. Navy is not a "profit" oriented organization, there is much concern today within the Supply Corps for buying the right items and in the right quantities. The procurement and placement of the correct set of spares on a ship is a difficult and delicate issue with inherently many trade-offs. Positioning less than the optimal range and number of spares, for critical equipments, might lower A_0 for the equipments in question and possibly the ship. It is also detrimental to position too many spares onboard the ship. This scenario may cause:

(1) excessive inventory and inventory accuracy problems,

(2) increased requirement for storeroom space, and

(3) increased opportunity costs due to decreased available budget.

An effective method to determine system interactions is through the use of simulation. Several reasons to simulate, as stated by Banks and Carson [Ref. 3], which are relevant in this case are:

(1) Simulation enables the study of, and experimentation with, the internal interactions of a complex system or of a subsystem within a complex system.

(2) By changing simulation inputs and observing the resulting outputs, valuable insight may be obtained into which variables are most important and how variables interact.

(3) Simulation can be used to experiment with new designs or policies prior to implementation, so as to prepare for what may happen.

These three general statements have significant appeal when discussing the use of simulation in building spare suites for critical and highly expensive ship systems. The inherent shortcomings of the ACIM model, due to model assumptions discussed later in the thesis, and the fact that ACIM is not directly related to operational missions support the justification for simulation. Finally, the current widespread availability of mainframe and micro computer equipments and simulation languages makes operational simulation an excellent and cost effective method to utilize in refining the Navy's sparing methodology.

C. THESIS OBJECTIVE AND SCOPE

This thesis proposes a procedure which uses the TIGER simulation model to refine a suite of spares for a ship subsystem as determined by ACIM. This procedure takes the output, the recommended range and depth of spares, from the

ACIM model and uses it as input into the TIGER simulation model in order to establish a "bad actor" list (those parts which cause the most downtime). This list will in turn be used to modify the original set of spares as input for another TIGER run to measure system availability. The precise methodology follows the one originally proposed by Judge and Luetjen [Ref. 1]. The procedure ensures attainment of a target A_o at minimum cost by structuring and refining the sparing process. The complete iterative process uses the sparing information from NAVSUP's sparing model along with the simulation capabilities and output of NAVSEA's TIGER program.

The organization for the rest of the thesis is as follows. Chapter II describes and discusses the assumptions and techniques utilized in the ACIM. Chapter III describes the TIGER simulation model, its current usage and capabilities with respect to the sparing process. Chapter IV provides the hypothesis, measures of effectiveness, and the proposed sparing methodology. Chapter V describes the NAVSTAR global positioning system radio receiver (GPS - 5), an example system to illustrate the technique proposed herein. Chapter VI provides the conclusions and recommendations concerning the use of the TIGER simulation model in the proposed "refined" sparing process. To supplement the presentation described above, Appendix A provides an overview of availability concepts and the complexity of estimating operational availability, Appendix B provides an overview of the Navy's inventory system with specific attention paid to the retail (consumer) shipboard level, and Appendix C provides a brief description of the sparing models currently utilized for building COSALs.

II. ACIM METHODOLOGY

A. MODEL INTRODUCTION

ACIM is a stationary multi-echelon model based on Markov process and queuing theory. It is capable of determining spare suites for inventory at several levels of the system, (i.e., wholesale, retail, etc.). However, its use in the Navy is limited by the following CNO directives:

1. The model will be utilized to compute stockage quantities only at the consumer level for operationally significant equipments,
2. Each application of the model must be approved by CNO (OP-41),
3. If it is concluded that increased supply support would improve $\hat{A}_0$ by at least five percentage points, and if at least five percentage points is required to achieve the CNO goal for $\hat{A}_0$, then the use of ACIM can be considered, and
4. Controls will be established to ensure that the continued requirement for ACIM's use is reassessed annually.

In this thesis, ACIM will be utilized as a single level inventory model to determine the level of sparing at the consumer (retail) level. The assumptions of the ACIM model are as follows:

1. External demands on supply are stationary and compound-Poisson distributed.

2. For each spare part issued, one part is ordered as replacement.

3. If the same part appears in different locations in a system, each part is treated as a unique item in the model.

4. MTTR and MTBF are defined as constants. MTTR includes all equipment repair related down time that are not supply related.

5. Component failures are independent.

6. When a system fails due to a part failure, the system does not operate again until the failed part is replaced.

ACIM uses an iterative marginal analysis of parts stocked to minimize MLDT. ACIM is designed to minimize the time that an equipment is not operational due to a lack of parts, thus maximizing $\hat{A}_o$.[1]

---

[1]FMSO criticized the definition of $\hat{A}_o$ in that by using the "uptime divided by total time", $\hat{A}_o$ is affected by the length of idle time, which is policy dependent, [Ref. 4]. A recommended alternative definition for $\hat{A}_o$ depended only on estimates of quantities inherent to the system. The recommended definition for $\hat{A}_o$ was:

$$\hat{A}_o = MT\hat{O}TBF \;/\; (MT\hat{O}TBF + M\hat{T}TR + M\hat{L}DT)$$

where $MT\hat{O}TBF$ is the <u>estimated</u> Mean Total Operating Time Between Failures. Although this criticism of the definition of $\hat{A}_o$ was acknowledged by higher authority, Equation (1) was chosen as the estimate of $\hat{A}_o$ to be used in DoD.

B. ALGORITHM DESCRIPTION

Rewriting ACIM's estimate of A_o, Equation (1), we obtain:

$$\text{Goal MLDT} = (\hat{MTBF} / \hat{A}_o) - \hat{MTBF} - \hat{MTTR} \qquad (2)$$

Note: If the Goal MLDT is less than 15 hours, it is defaulted to 15 hours

The algorithm utilized by ACIM computes stocking levels for system components which minimizes MLDT for a given budget. During each iteration, the stocking level of the spare which yields the largest marginal decrease in MLDT per dollar is increased by one unit (See Figure 1). In the calculation of the marginal decrease in MLDT, ACIM treats items with multiple applications in a particular system as different items. This allows ACIM to employ the common technique of "parts counting", assuming that all parts operate in series. [Ref. 5]

The mathematical description of the model, as described in the ACIM Handbook [Ref. 6], is provided below. The model consists of the following definitions and equations in which i denotes an arbitrary item in equipment a (i may be a itself) and, u represents an arbitrary facility in the support system:

$$M_{iu} = D_{iu} + T_{iu} \qquad (3)$$

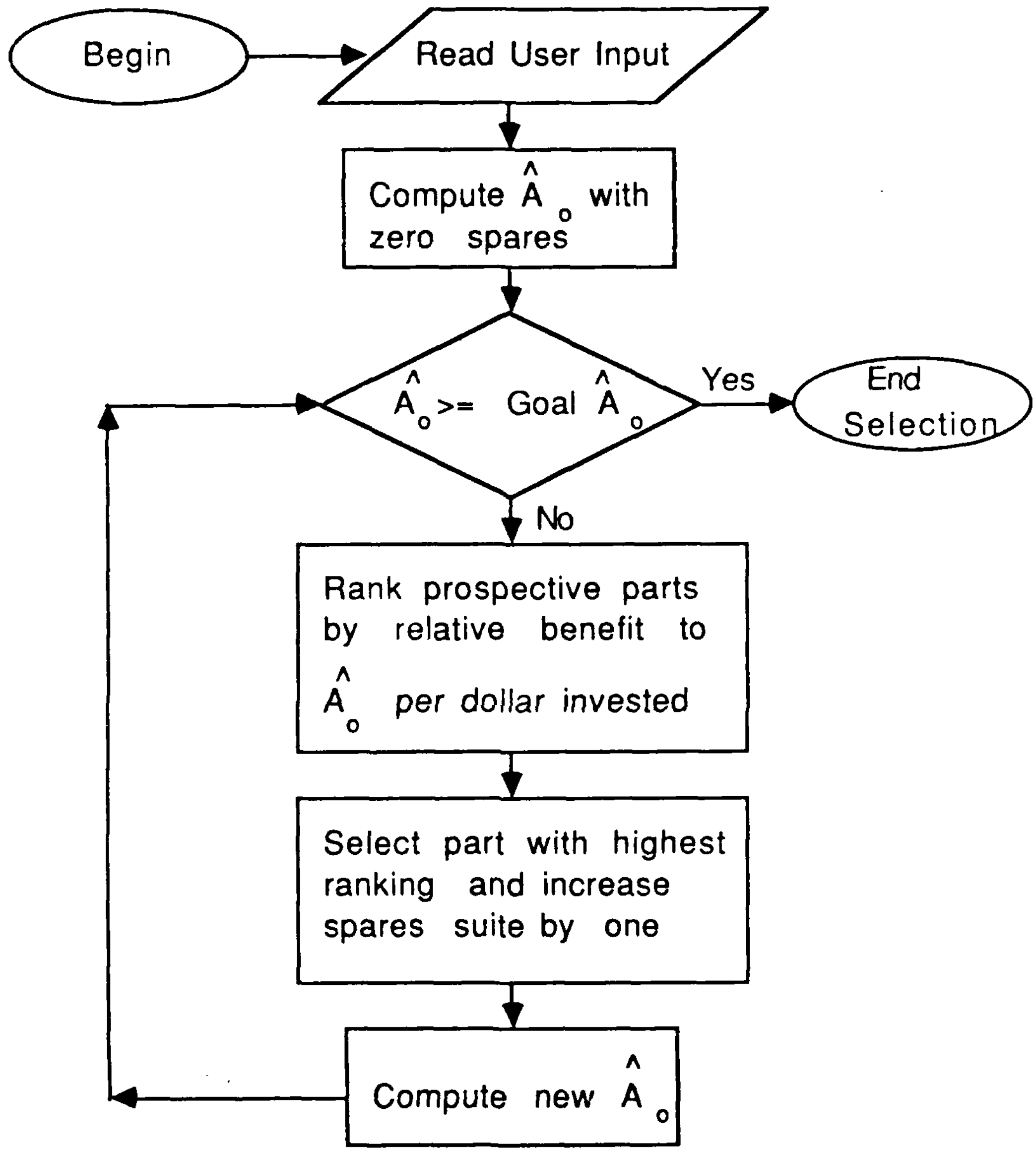

Figure 1. ACIM Marginal Analysis Technique

where

M_{iu} = mean time to return a failed unit of item i at location u to a serviceable condition.

D_{iu} = expected time delay per demand upon inventory for item i at location u.

T_{iu} = mean time to repair item i at user location u (for equipment repair).

In equation 3, the factor T_{iu} represents the marginal mean time to repair item i through replacement from stock or repair of failed subordinate parts. Included are all repair related functions such as documentation, fault isolation, removal and replacement and system checkout. These factors are assumed to be given as constants.

$$D_{iu} = \frac{1}{\lambda_{iu}} \sum_{x > S_{iu}} (x - S_{iu}) p(x; \lambda_{iu}, T_{iu}) \quad (u = 0, 1, 2, \ldots, U) \qquad (4)$$

S_{iu} = stock level of item i at location u.

λ_{iu} = expected number of demands upon inventory for item i at location u.

$p(x; \lambda_{iu}, Tiu)$ = probability of x units of stock reduction for item i at location u.

In equation 4, the summation term gives the expected number of backorders for a stock of S_{iu}. This is equivalent to the expected length of time the stock is in a backorder status. Dividing by the expected number of demands per time unit gives the expected delay in satisfying a demand. The time unit in ACIM is days. Values for λ_{iu} are assumed to be given by input data in ACIM.

$$T_{iu} = \gamma_{iu}(L_{iu} + L'_{iu}) + (1 - \gamma_{iu})(R_{iu} + R'_{iu}) \qquad (5)$$

where

γ_{iu} = probability that a demand for item i upon inventory at location u results in a loss (discard or sent elsewhere for repair) which must be replaced through resupply.

L_{iu} = average resupply lead time assuming stock is available at the resupply source.

L'_{iu} = additional resupply lead time due to expected shortages at the resupply source.

R_{iu} = average shop repair cycle time assuming availability of spares for items within i at the next lower indenture level.

R'_{iu} = additional shop repair cycle time due to expected shortages of spares for items within i at the next lower indenture level.

In equation 5, the factors γ_{iu} are assumed given by input data. The factors L_{iu} and R_{iu} are assumed to be given by input data as constants for each location. The first term (involving resupply lead times) represents losses from stock due to scrap or units sent to higher level repair facilities. The second term represents losses due to amounts cycling through local repair.

$L'_{iu} = D_{iu}$ $\quad (u = 1,2,\ldots,U)$ (6)

$L'_{i0} = D_{iv}$ $\quad$ where v is the resupply source for location u = 0.

$= 0$ $\quad$ if location 0 has no resupply source.

Equation 6 states that the additional delay in obtaining resupply is equal to the expected delay per demand upon stocks at the resupply source.

$$R'_{iu} = \frac{\sum_{j \in i} \lambda_{ji} M_{ju}}{\sum_{j \in i} \lambda_{ji}} \tag{7}$$

where j identifies items within i at the next lower indenture level.

$R'_{iu} = 0$ $\quad$ if i has no subordinate parts.

Equation 7 states that the additional delay in repairing an assembly is equal to the weighted average of expected delays per demand upon stocks at the next lower indenture level.

$$A_{au} = \frac{1}{(1 + \lambda_{au} M_{au})} \tag{8}$$

where

A_{au} = fraction of time equipment a is available for use at location u (defined only for locations u which operate the equipment).

λ_{au} = expected number of demands upon inventory for equipment a at location u.

Equation 8 gives the operational availability of the equipment in terms of factors defined by previous equations. With proper interpretation of terms, this definition can be translated into other expressions for $\hat{A}_o$.

The above definition of the model is recursive on "item" within the parts hierarchy and "location" within the support system hierarchy. If stock levels are given for all items at all locations, a recursive procedure using the equations may be applied to determine corresponding operational availabilities of the equipment at all user locations. The recursion starts with items at the bottom of the parts hierarchy. For such items and locations, additional resupply and repair times (equations 6) and 7)) are zero, and expected delays can be calculated directly using equations 4) and 5). These delays can be used in equations 6) and 7) to calculate additional resupply and repair times. Expected delays for these items and location can then be determined by equations 4) and 5).

The overall objective of the ACIM model is to determine inventory levels for all items and all stockage facilities such that the expected operational availability of the equipment is maximized for a given inventory budget or, conversely, to find inventory levels which achieve a given operational availability at least cost. This objective can be explicitly stated as, "Find values S_{kv} for all items k in equipment a and locations v in the support system which minimize $D = D_{au}$ for all user locations u subject to:

$$\sum_{k,v} c_k S_{kv} = B$$

where,

c_k = unit cost of item k

B = given budget for spares procurement"

Equations 3) and 8) show that minimizing D_{iu} is equivalent to maximizing A_{au}, the operational availability of equipment a at user location u. A similar statement can be written for the converse objective of achieving a given value of A_{au} at least cost.

The ACIM optimal solution to the problem defined above is found by an iterative procedure based upon equations 3) through 8). First, however, a subproblem is defined and a solution procedure is given for the subproblem. An iterative application of the subproblem is then used to solve the original problem. Although not critical in the context of this thesis, the specifics of the subproblem formulation and solution are available in the ACIM Handbook.

C. MODEL SHORTCOMINGS

The model, in its current form, contains some inherent shortcomings which need to be highlighted. First, ACIM considers that all system components operate in series. That is, when one part fails, the system is considered "down" until the failed part is replaced with a good part. Although computationally simpler, this assumption often does not reflect actual system characteristics. For example, when the system components operate in parallel (standby), ACIM clearly underestimates the operational availability. In addition, systems which are capable of operating in a partial mode (i.e., partial mission capable) are not accommodated by ACIM. Second, spares selection is based solely on the use of operational availability, utilizing the means (MTBF and MTTR) of assumed distributions as constants. Moreover, ACIM maximizes the operational availability without regard to a ship's mission. It is more sensible that spare suites should be stocked at a level which ensures a sufficiently high $\hat{A}_o$ given the intended operational mission.

D. SUMMARY

ACIM provides a logical, systematic approach for selecting spares for critical ship systems by using the operational availability, $\hat{A}_o$, as a measure of effectiveness. The model allows for the maximizing of the estimated A_o given a certain budget or achieving a target A_o while minimizing costs. Because ACIM uses $\hat{A}_o$ exclusively as the measure of effectiveness (MOE), without regard to the intended ship's mission, there is nothing to link spares selection to mission success. In Chapter III, we describe a procedure using the TIGER simulation model to establish such a link.

III. TIGER SIMULATION

A. MODEL INTRODUCTION

TIGER is a family of computer simulation programs written in ANSI 77 FORTRAN which was developed and is maintained by NAVSEA (Code 05MR). The simulation is a discrete, event-driven model which uses Monte Carlo techniques to estimate system parameters given the estimated MTBF and MTTR of the system components and a repair policy. Figure 2 provides an overview of the TIGER run diagram.

B. CURRENT USAGE

NAVSEA (Code 05MR) uses the TIGER program to measure and evaluate complex weapons systems in terms of the estimated reliability, maintainability and availability (RMA) characteristics of Navy systems. The RMA system analysis begins early in the design and development stages to ensure implementation of the most cost effective design which meets or exceeds original system requirements. The TIGER program makes use of numerical representations of the basic reliability blocks in the form of reliability block diagrams (RBD) which describe failure characteristics of a system. Figure 3 compares a simple example of a RBD to a functional diagram. The program has the ability to accommodate not only

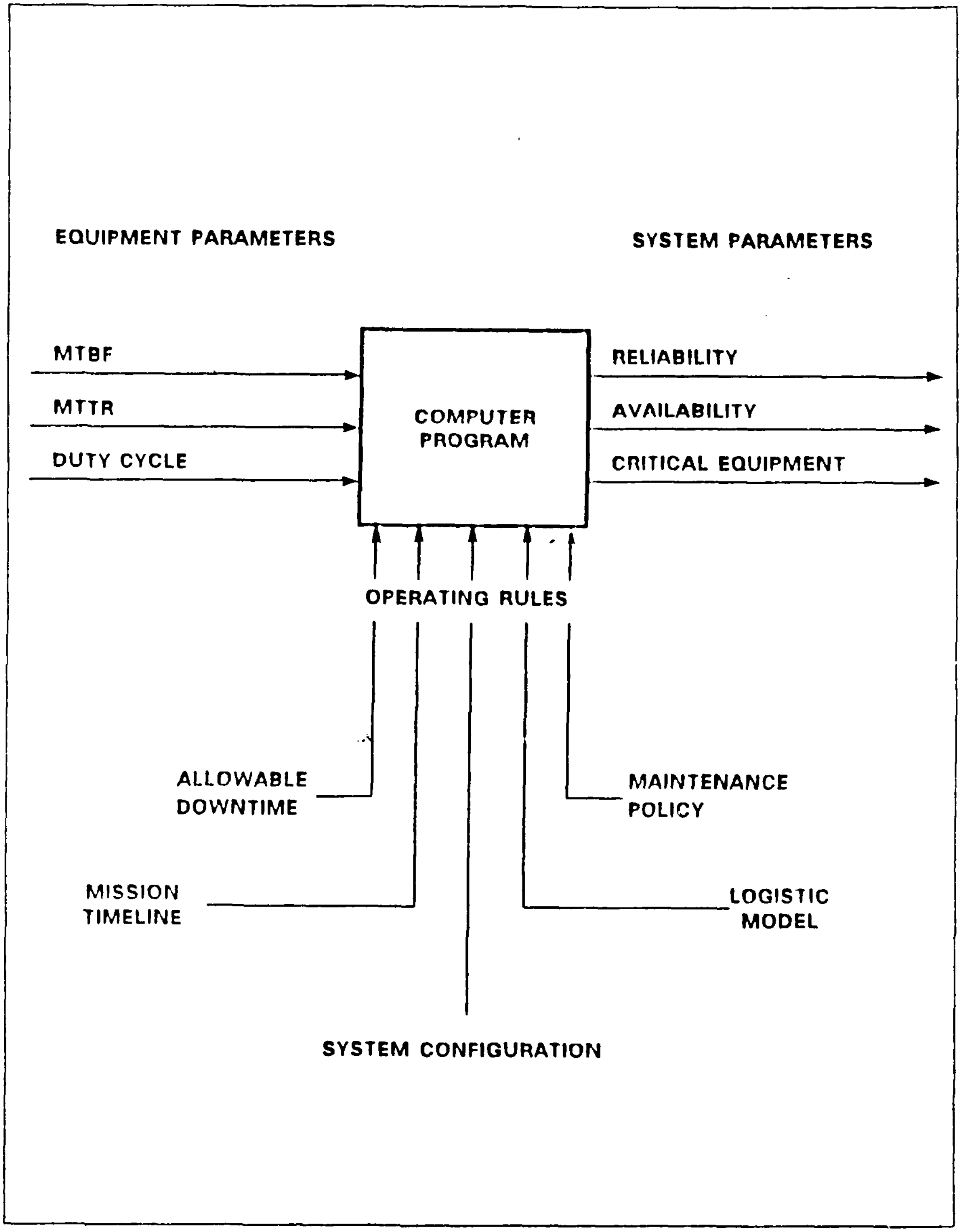

Figure 2. TIGER Run Diagram [Ref. 7]

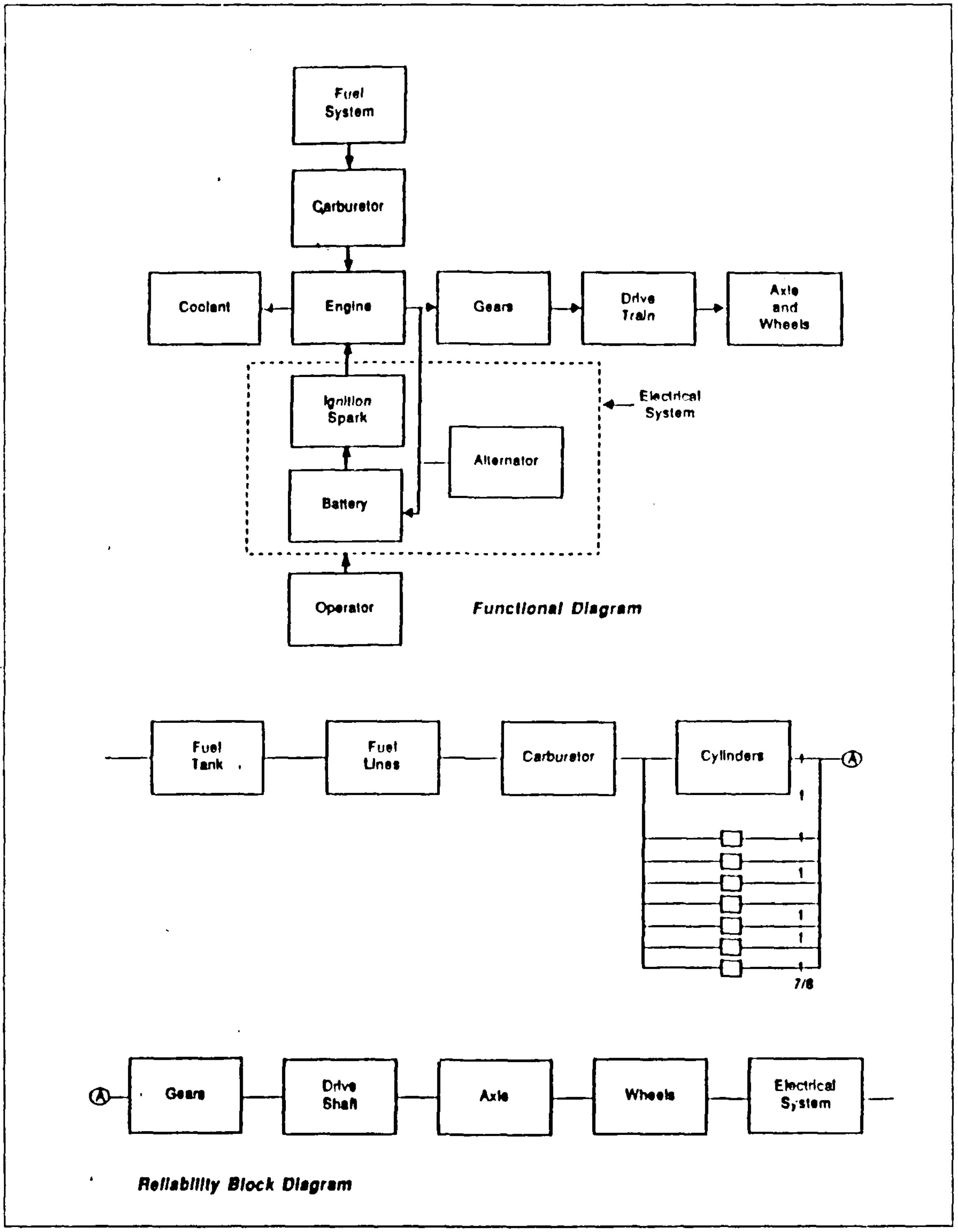

Figure 3. Reliability Block Diagram [Ref. 8]

series configurations but also a variety of parallel systems (i.e., cold and hot standby). In this way, the TIGER program possesses a major advantage over many other mathematical models. It can be used to evaluate large, complex systems under a variety of configurations, operating rules, and different scenarios.

C. ALGORITHM DESCRIPTION

TIGER uses Monte Carlo simulation techniques which consist of, and are driven by, the following five events:

1. Beginning of Mission
2. Change of Equipment Configuration Requirements within the Mission
3. Equipment Failure
4. Equipment Repair
5. End of Mission

The beginning and ending mission times as well as configuration change times are data input. The mission begins with all equipment "up" and all stocks up to allowance (if using the spares inventory model). With data input of components' estimated MTBFs and MTTRs and a string of uniformly distributed random numbers, times to system failures and repairs are calculated. This is done using the assumption of exponentially distributed event times with means of MTBF and MTTR, respectively. Then, based on the configuration, system "up" and "down" times are used to estimate system performance. With the number of trials predetermined by the user, the simulation is repeated with a different string of random numbers for each trial and the simulation results are then averaged. Figure 4 provides the TIGER program flow diagram.

D. TIGER Outputs

TIGER output consists of a seven part file as provided below:

1. User Input Echo
2. Simulation Progress Reports
3. Final Figure of Merit Reports
4. Equipment Performance Statistics
5. Critical Equipment Lists
6. Restricted Erlang Distribution Model (REDM)
7. Maintainability Report

Although several parts of the output file will be used in the analysis, the most critical to the method used in this thesis are the critical equipment lists and final figure of merit reports. TIGER output offers five critical equipment lists. They are:

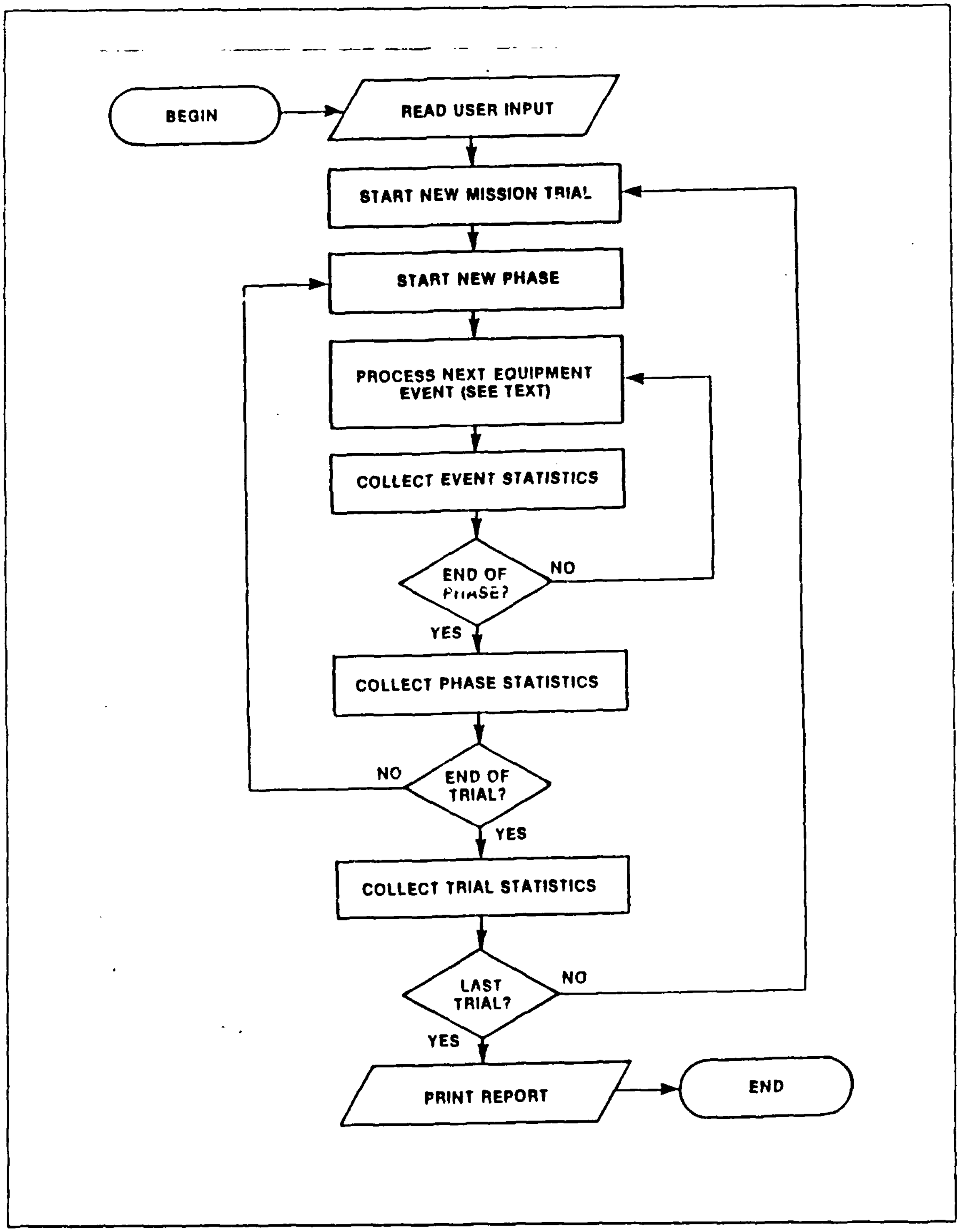

Figure 4. TIGER Program Flow Diagram [Ref. 7]

1. Unavailability of Critical Equipment by Equipment Number
2. Unavailability of Critical Equipment by Equipment Type
3. Proportional Responsibility of Critical Equipment by Equipment Type
4. Unreliability of Critical Equipment by Equipment Number
5. Unreliability of Critical Equipment by Equipment Type

TIGER estimates average system availability, denoted by $\hat{A}_{om}$, and provides the value as part of the figures of merit. A_{om} is estimated in TIGER as follows:

$$\hat{A}_{om} = \frac{\text{TOTAL SYSTEM UPTIME IN ALL TRIALS}}{\text{TOTAL TIME}}$$

The values obtained will be compared with the desired A_o goal. This value combined with the critical equipment lists will be used to determine which (if any) of the parts within the system should receive an adjustment to their initial, ACIM computed stocking level. If adjustments are determined to be desirable, they will be made and another set of simulation trials will be performed.

E. SUMMARY

Although TIGER is currently used only to measure and evaluate RMA characteristics of Navy systems, TIGER provides several output options which expand its usefulness. In particular, the critical equipment lists option provided by the program allows for a thorough review of those subcomponents which contribute the most to the system's "unreliability." Thus, through their use and the use of initial stocking levels, those levels can be adjusted either up or down to meet or exceed the system's operational availability goals.

IV. SPARING METHODOLOGY

A. HYPOTHESIS

ACIM, coupled with the iterative use of TIGER, provides a refined sparing process which better approximates, at a reduced cost, the sparing requirements necessary to achieve a target system operational availability. Given the fact that these models are already in use by the Navy, the method proposed in this thesis is immediately implementable and has the potential of providing a better allocation of spares for critical and highly expensive ship systems.

B. MEASURES OF EFFECTIVENESS

The two measures of effectiveness utilized in this sparing process are:

$$(1) \quad \hat{A}_o = \frac{M\hat{T}BF}{M\hat{T}BF + M\hat{T}TR + M\hat{L}DT}$$

(ACIM)

$$(2) \quad \hat{A}_{om} = \frac{\text{TOTAL SYSTEM UPTIME IN ALL TRIALS}}{\text{TOTAL TIME}}$$

(TIGER)

These MOE's are described in Chapters II and III, respectively.

C. METHODOLOGY

Assuming that the criteria, as described in Chapter II, are met for using ACIM sparing for a particular ship system, two major parts of the methodology will be the use of the two models: ACIM and TIGER. Equally important to the method and use of these models, is the critical preliminary review of the system data prior to input into the models. Both models are based on the assumption of exponential times to failure (and repair). The "memoryless property" of the exponential distribution makes it necessary to first manually review the system component list and exclude any items which are known to exhibit "wear-out" tendencies. Spares for these items should be computed off-line with the use of historical data and recommendations from maintenance personnel. Following the guidelines set forth in the ACIM Handbook and using the established estimated system parameters (i.e., technical replacement factors (TRF), price, etc.), the next step is to set the following parameters and perform an ACIM run:

1. A_o Goal
2. Cost Ceiling
3. Mission Time
4. MTTR
5. MLDT
6. Duty Cycle

If the A_o goal has been met, the spare quantities obtained using ACIM are those quantities which will be used as the initial spares in the TIGER simulation(s). TRF is the number of times per year an item will be requisitioned from the supply system by an organizational user. If the TRF's are the only figures provided with the spares information, off-line computations must be made to obtain the associated MTBF which is used by TIGER. The formula used to compute MTBF in this thesis is as follows:

$$TRF = \frac{DC}{MTBF}$$

where,

DC = Duty Cycle in Hours / Year
MTBF = Mean Time Between Failure
= Operating Hours / # Failures

For this analysis, the TRF's used were based on a duty cycle of 6000 operating hours per year (see Appendix D). The next system information needed to perform the TIGER simulation is the RBD of the system. Prior to 1980, only some selected critical Navy systems were procured with RBD information. This made the use of TIGER for COSAL sparing impossible if the RBD could not be obtained or easily produced. This potential problem was alleviated in 1980 with the publication of MIL-STD-785B which states, "As the design evolves, a reliability block diagram shall be developed and maintained for the system/subsystem with associated allocations and predictions for all items in each reliability block." [Ref. 9] Following the guidelines in the TIGER Manual and the proposed method by Judge and Leutjen [Ref. 1], Phase 1 of this methodology is performed. A mission timeline and system operating rules are developed and combined with the initial set of spares as computed by ACIM. Utilizing the computed values for $\hat{A}_{om}$, the target A_o and the critical equipments list, a decision is made concerning the spares levels. If the computed $\hat{A}_{om}$ is less than the target A_o, one spare is added to the original suite. The choice of which component level to adjust is found by reviewing the critical equipment list and picking the item which provided the most "unreliability" to system $\hat{A}_{om}$. Following this, another simulation is performed and the same comparison of computed $\hat{A}_{om}$ and target A_o is made. This iterative process of TIGER simulations is continued until a satisfactory estimated A_o is attained. Similarly, if the computed $\hat{A}_{om}$ exceeds the target A_o, then one spare is taken away from the original spare suite. The component which should have its level decreased is the one which provides the least to system "unreliability", as provided by the critical equipment list. When reviewing the critical equipment list in this case, a check should be made to see that all components on the original spares list are on the critical equipment list. This is because components which did not fail during the simulation would not show up on the list. A component which did not fail and has an original spare quantity greater than zero should have its original level decreased by one. If there is more than one to choose from in this category, the sparing level of the most expensive component should be reduced. In the event that all spare candidates appear on the critical equipment list, the component which should have its original sparing level (greater than zero) reduced by one is the one which has contributed the least to system "unreliability." With Phase 1 now complete (i.e., initial ACIM computed levels adjusted and computed A_{om} meeting or exceeding target A_o), Phase 2 begins. The process in Phase 2 is designed to reduce the stock levels obtained from Phase 1 without reducing the A_{om} below the target A_o, thus reducing the total cost of the spares suite. Utilizing the "Summary of Spares Used" listing from the final TIGER simulation from Phase 1, a review is made of the decimal portion of the "Spares Used Per Mission" listing. If this is greater than or equal to 0.10, the spares used per mission value is rounded up. We will denote this rounded value as "A". This value is then compared to the modified stock level from Phase 1, which will be denoted as

"B". The new modified sparing levels for each system component is then computed as the Min {"A", "B"}. A final TIGER simualtion should be performed to ensure that the estimated A_{om} still meets or exceeds the target A_o. Figure 5 provides a flow diagram of the method.

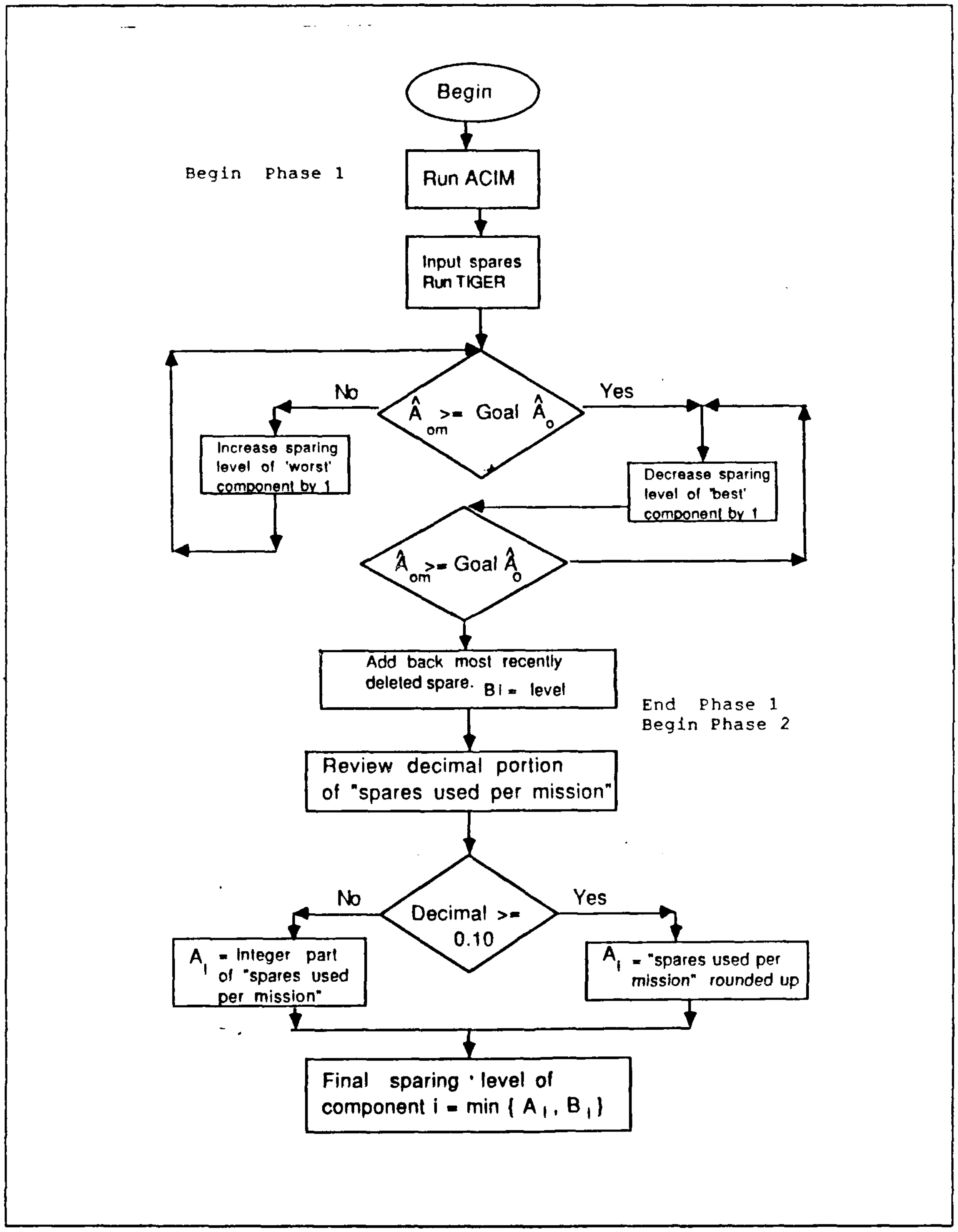

Figure 5. Sparing Methodology Flow Diagram

V. GPS-5 RECEIVER SYSTEM

A. SYSTEM CHARACTERISTICS

"The NAVSTAR Global Positioning System (GPS) is an all-weather, spaced-based navigation system" which was under development by the Department of Defense (DoD) in 1985 and was planned to attain full operational capability by the end of 1989. [Ref. 10] It is used to provide precise position, velocity and time in a common reference system, anywhere on or near the Earth on a continuous basis. The GPS-5, the shipboard installed equipment used in the GPS system, consists of three major units; the antenna assembly (FRPA-3), a receiver processor unit (RPU) and a control display unit (CDU).

B. SYSTEM CONFIGURATION

There are two configurations currently employed by the Navy, the surface and sub-surface configurations. The surface configuration includes two CDU's, one FRPA-3 and one RPU. The sub-surface configuration consists of only one CDU and RPU (i.e., no FRPA-3 antenna). The surface configuration is the one used for the analysis in this thesis. Appendices D and E provide the GPS-5 system parameters and configuration, respectively. The primary objective during the design and development phases was "to design and build a family of GPS user sets at a minimum life cycle cost..." Use of the TIGER model will show that the life cycle costs of the GPS-5 can be lowered, as compared to ACIM sparing, by providing a better set of spares without reducing the estimated operational availability.

VI. CONCLUSIONS AND RECOMMENDATIONS

A. SIMULATION RESULTS

Organizational stocking levels for the GPS-5 system were computed using the ACIM model. The unit costs and quantities for the spares are provided in Appendix F. Utilizing the sparing information from the ACIM output (the ACIM, FLSIP and Mod-FLSIP sparing levels), a TIGER simulation was performed for each of the three sets of spares to compare their estimated A_{om} and associated costs. Appendix G provides the FLSIP and Mod-FLSIP sparing levels utilized. Figure 6 provides the cost per ship versus operational availability showing the relative costs of each alternative, as measured by TIGER. The simulation was performed with 1000 repetitions, utilizing the system parameters provided in Appendix D with an unlimited amount of spares at the intermediate level. It should be noted that no depot level spares were required for any of the simulations.

Expecting that the organizational spares reorder policy utilized in the simulation would have a major impact on the computed $\hat{A}_{om}$, two sets of rules were established in TIGER for the simulations. They are as follows:

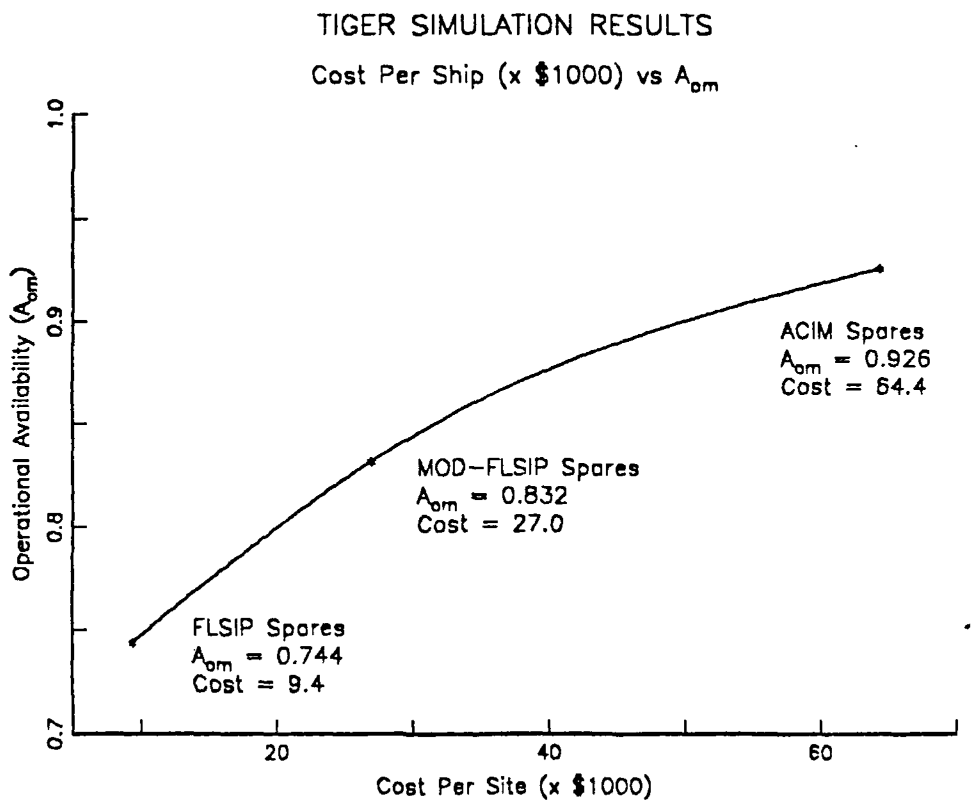

Figure 6. Current Sparing Cost Comparison

Rule 1: Initial organizational sparing levels would be provided by ACIM. Depot level spares would be unlimited. With MLDT set at 17.5 days (420 hours), no organizational spares would be ordered from the intermediate level until the balance at the organizational level was zero.

Rule 2: Initial organizational sparing levels would be provided by ACIM. Depot level spares would be unlimited. With MLDT set at 17.5 days (420 hours), replacement organizational spares would be ordered when the on-hand quantity reached 75% of the initial allowance. Due to the small number of initial spares for the GPS-5 system, this effectively meant a one-for-one reorder.

It should be noted that although the reorder rules were different, the spares suite, and associated costs, utilized with Rules 1 and 2 in the simulations were the same. With these two operating scenarios established, two initial simulations were performed. The results are as follows:

Operational Availability ($\hat{A}_{om}$)

Rule 1	Rule 2
0.926	0.973

Clearly, the spares reorder policy has an effect on the measured $\hat{A}_{om}$. With the two simulation outputs, the critical equipment lists were utilized to determine which components provided the most in "unreliability" (under Rule 1) and the least in "unreliability" (under Rule 2). Since Rule 1 provided an estimated A_{om} below our target of 95%, additional spares were needed to reach our goal. Similarly, since Rule 2 provided an estimated A_{om} which exceeded our target, the number of spares could be reduced while still staying above our 95% goal.

In performing the simulations with Rule 1, four iterations of Phase 1 of the method were required before we reached our goal of 95% operational availability. Figure 7 provides the simulation results. With Rule 2, seven iterations of Phase 1 of the method were required to reduce the total cost of the spare suite and still meet or exceed the operational availability goal of 95%. Figure 8 provides those simulation results. Appendix H provides the ACIM stock level adjustments made during Phase 1 of the methodology. Since Rule 2 most closely resembles the current method of ordering shipboard spares, it was used in Phase 2 of the methodology. Utilizing the method described in Chapter V, newly modified sparing levels were computed by reviewing the "Spares Used Per Mission" listing. The final recommendation GPS-5 spares suite is provided in Appendix I along with the original ACIM sparing levels for easy comparison. The final TIGER simulation was performed with the Phase 1 and 2 modified sparing levels and an $\hat{A}_{om} = 0.949$ was obtained. A summary of the methodology results are provided below:

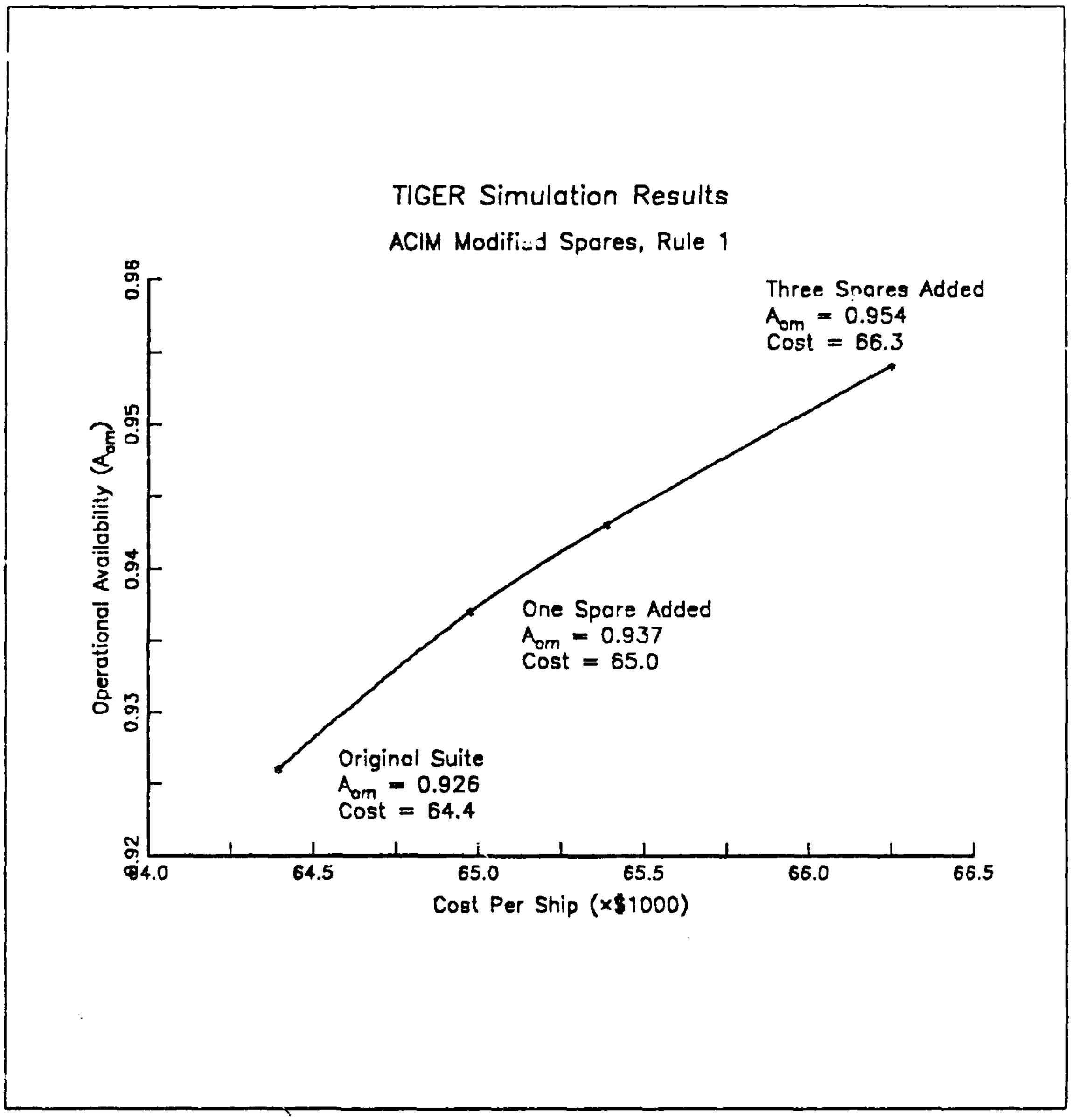

Figure 7. **TIGER Simulation Results, Rule 1**

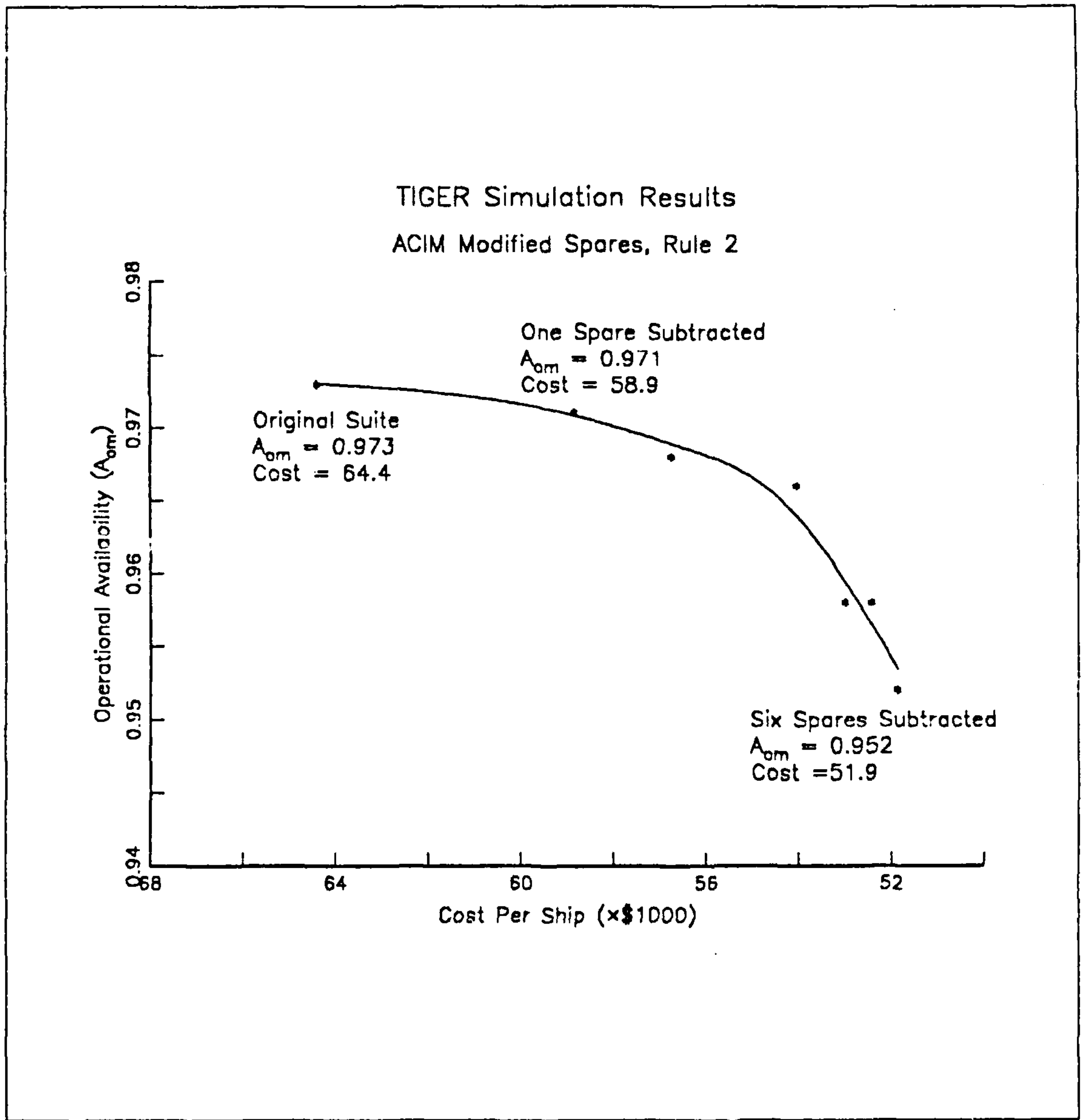

Figure 8. TIGER Simulation Results, Rule 2

Methodology Results

	A_o Target	$\hat{A}_{om}$ Achieved	Cost
ACIM	0.95	0.973	$66,394.92
ACIM (Rule 2, Phase 1)	0.95	0.952	$51,862.39
ACIM (Rule 2, Phase 2)	0.95	0.949	$29,835.39

B. CONCLUSIONS

By utilizing the TIGER simulation program along with establishing two sets of replenishment rules, it was possible to display TIGER's potential in refining COSAL spares suites computed by ACIM, adjusting the levels either up or down depending on the need. In Rule 1, Phase 1, we did not attain our target A_o and therefore used TIGER to determine which sparing levels to increase to attain our goal. In Rule 2, Phase 1, we exceeded out target A_o and therefore utilized TIGER to determine which sparing levels to decrease. In both cases, the proposed methodology allowed for the:

(1) realistic simulation of a ship's operating timeline and its use of onboard spares,

(2) determination of the expected level of operational availability provided by those spares, and

(3) adjustment of stocking levels to attain A_o goals, thus refining the spares suite at the shipboard level.

Finally, utilizing Rule 2, Phase 2 of the methodology, a spares suite was computed which essentially achieved our target $A_o = 0.95$ at a dramatically reduce cost as compared to using ACIM alone. The above result with the GPS-5 system clearly demonstrates that:

(1) ACIM as a sparing model is not cost effective, and

(2) the TIGER simulation program, when combined with ACIM in the manner described in this thesis, provides an effective means of achieving the target operational availability at a reduced cost.

C. RECOMMENDATIONS

Recommendations for further study of the use of TIGER in the sparing process are as follows:

1. Modification of TIGER's computer code to build in dependence of failure times between system components to determine if dependent failure times will dramatically effect the sparing levels for a ship system.
2. Validation of TIGER's FLSIP and Mod-FLSIP spares generator and evaluation of TIGER as a "stand alone" sparing model to determine if the initial use of a sparing model such as ACIM is necessary for the method described in this thesis.
3. Analysis of TIGER's use in (a) the process of building separate spare suites for several critical ship systems and (b) comparison of those levels with a shared pool of spares to determine if TIGER can be used to identify potential cost savings when building a combined COSAL.
4. Analysis of TIGER's use in the process of building spare suites using failure and repair times whose distributions are other than that of the exponential (i.e., Gamma, Phase-type) to determine if there would be any difference in sparing levels.

APPENDIX A

AVAILABILITY CONCEPTS

Availability has been defined as the probability that an item will be capable of performing its specified function when called for at any random point in time. The exact mathematical equation for availability can be very complex. Even when times to failure and repair are exponential, other factors such as active/ passive standby, number of spares, restricted/ unrestricted repair and failure detection make the mathematics for instantaneous and steady state availability very complex. Nearly all DoD documents that address availability use an approximation to availability. Kozlov and Ushakov [Ref. 11] have one of the most comprehensive treatments of reliability of repairable systems and availability. Their book provides approximately 50 tables that give equations for system reliability, availability and related quality indices for as many different descriptions of system redundancy and repair capability.

NAVORD OD 43251 [Ref. 12] provides a derivation of steady-state availability for the case of one item with no standby and unrestricted repair capability. Pointwise availability, A(t), defined as the instantaneous probability that a system is up at time t is used to obtain the interval availability A_T during intervals of length T. The average value, assuming that the probability distribution on demand time is U[0,T], is then:

$$\bar{A}_T = \frac{1}{T}\int_0^T A(t)\,dt$$

If we further assume exponentially distributed failure and repair times with means $\frac{1}{\lambda}$ and $\frac{1}{\mu}$, respectively, failure detection is immediate and initiation of repair is immediate, the pointwise availability can be obtained by solving a first order linear differential equation to give us:

$$A(t) = \frac{\mu}{\lambda + \mu} + \left[1 - e^{-(\lambda+\mu)t}\right] + A(\emptyset)\,e^{-(\lambda+\mu)t}$$

Assuming A(0) = 1 and substituting this into the equation for average availability gives:

$$\bar{A}_T = \frac{\mu}{\lambda + \mu} + \frac{\lambda}{(\lambda+\mu)^2\,T}\left[1 - e^{-(\lambda+\mu)T}\right]$$

This expression includes a steady-state term and a transient term. As T gets sufficiently large, it can be seen that the interval availability approaches a constant, steady-state availability:

$$A = \lim_{T\to\infty} \bar{A}_T = \frac{\mu}{\lambda+\mu} = \frac{\frac{1}{MTTR}}{\frac{1}{MTBF} + \frac{1}{MTTR}} = \frac{MTBF}{MTBF + MTTR}$$

Therefore, for a sufficient length mission, the steady-state term is often used as an approximation to measure A_o. This fact allows for a simplified measurement of an estimate for A_o. The steady state term derived in the NAVORD publication is the approximation which ACIM uses to perform its optimization techniques. In addition, TIGER's measure of average operational availability uses a similar form.

For additional, indepth analysis of mathematical models for operational availability, the reader is referred to Kozlov and Ushakov [Ref. 11].

APPENDIX B

THE NAVY SUPPLY SYSTEM

A. OVERVIEW

The United States Navy's inventory system is divided into three echelons or levels of inventory: wholesale, retail intermediate, and retail consumer. DoD Directive 4140.1 defines these levels as follows:

- Wholesale inventory: wholesale inventory manager has visibility and control at the national level.
- Retail intermediate inventory: inventory required between the consumer and wholesale levels to support a given geographical area, including area resupply and consumer level maintenance.
- Retail consumer inventory: material held strictly for the unit's own use or consumption.

Figure 9 provides a general overview of the Navy's three echelon inventory structure.

Due to the difficulty encountered in relating three inventory levels in one model, the Navy currently uses different mathematical models for calculating inventory levels for the three echelons of support. This thesis focuses on the retail consumer level and in particular, the shipboard consumer.

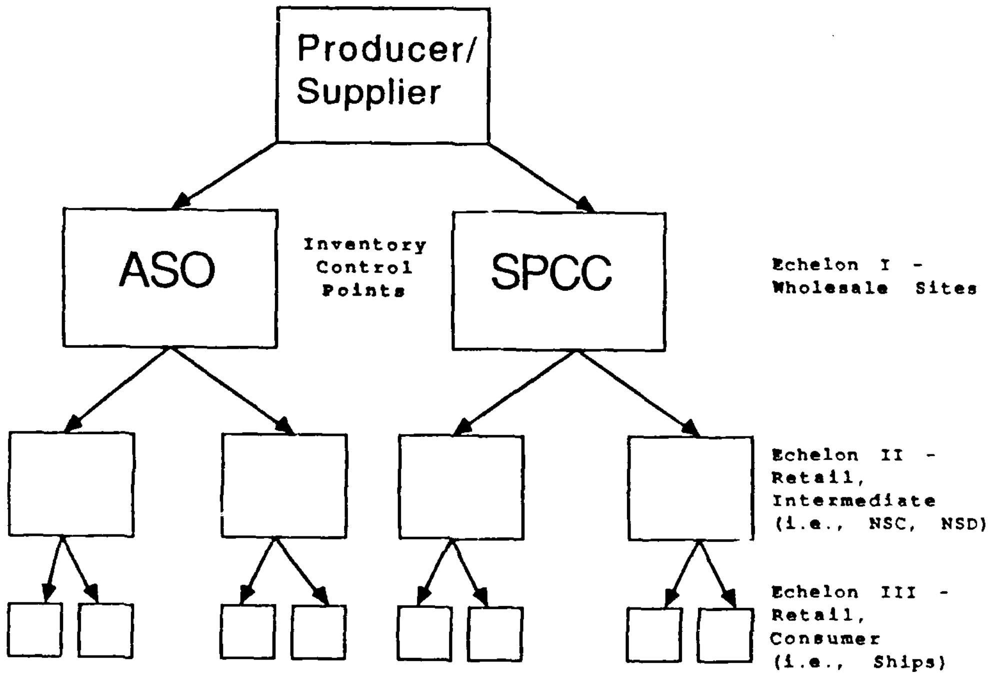

Figure 9. U.S. Navy's Three Echelon Inventory Structure

B. CONSUMER LEVEL

Retail inventory is the first echelon of support for the customer. The management of that inventory is extremely critical to A_o in that the inventory levels at an operating unit have immediate impact of the successful completion of its mission. The objective of the Navy retail inventory manager therefore, is to minimize the supply response time for material under their cognizance. The inventory control point (ICP) tasked with managing shipboard systems' inventory levels is the Ship's Parts Control Center (SPCC). There are several models used at SPCC to compute COSAL allowances. The COSAL specifies the range and depth of the onboard repair parts to be carried by the ship to sustain itself through maintenance for a specified period of time, usually ninety days. The three most common are known as FLSIP, Mod-FLSIP and ACIM.

COSAL allowance policies are known as the Fleet Logistics Support Improvement Program (FLSIP), established in 1964 and Modified-FLSIP, formulated in 1979. These two models are classified as "fixed protection level" models. They use the demand forecast to determine allowance levels and provide the same level of protection for all demand based items. Mod-FLSIP provides enhanced support for equipment related to a ship's primary mission. ACIM is an "optimized protection level" model used to compute COSAL levels for specific weapon systems when the standard protection models cannot achieve the readiness objective for those systems. Each specific application of ACIM must be approved by CNO prior to its use.

While the analysis and methodology used in this thesis will use the ACIM model, a general overview for the two fixed protection models, FLSIP and Mod-FLSIP will be provided. The overviews of the two models will illustrate that similar reasons exist as with ACIM which make the use of simulation desirable when building COSAL levels for critical ships' systems. That is, the models do not address the issues such as system usage, operational mission, maintenance guidelines, etc. Therefore, the set of spares ldeveloped using these models might not be optimal.

APPENDIX C

CURRENT SPARING MODELS

A. INTRODUCTION

The three basic models primarily used by the Navy in building spare suites for COSALs are the FLSIP, Mod-FLSIP and ACIM. These models do not attempt to address or optimize operational mission availability as a measure of effectiveness (MOE). However, each model is based on sound mathematics and modeling techniques and, therefore, serves a useful purpose in "building" towards an optimal spares suite.

B. FLSIP AND MOD-FLSIP

The FLSIP and Mod-FLSIP models are fixed level protection models based on the assumption that the number of items in demand in a specified time period has a Poisson distribution. As stated by Tersine, "For items of low demand, the discrete Poisson distribution is a very likely candidate for the demand distribution." [Ref. 13] Figure 10 shows how the fixed level protection model is used to obtain the number of spares required. Tersine goes on to point out that if the average demand is "large", the Poisson distribution is indistinguishable from the normal distribution. The Navy's FLSIP and Mod-FLSIP models make use of this fact by using a

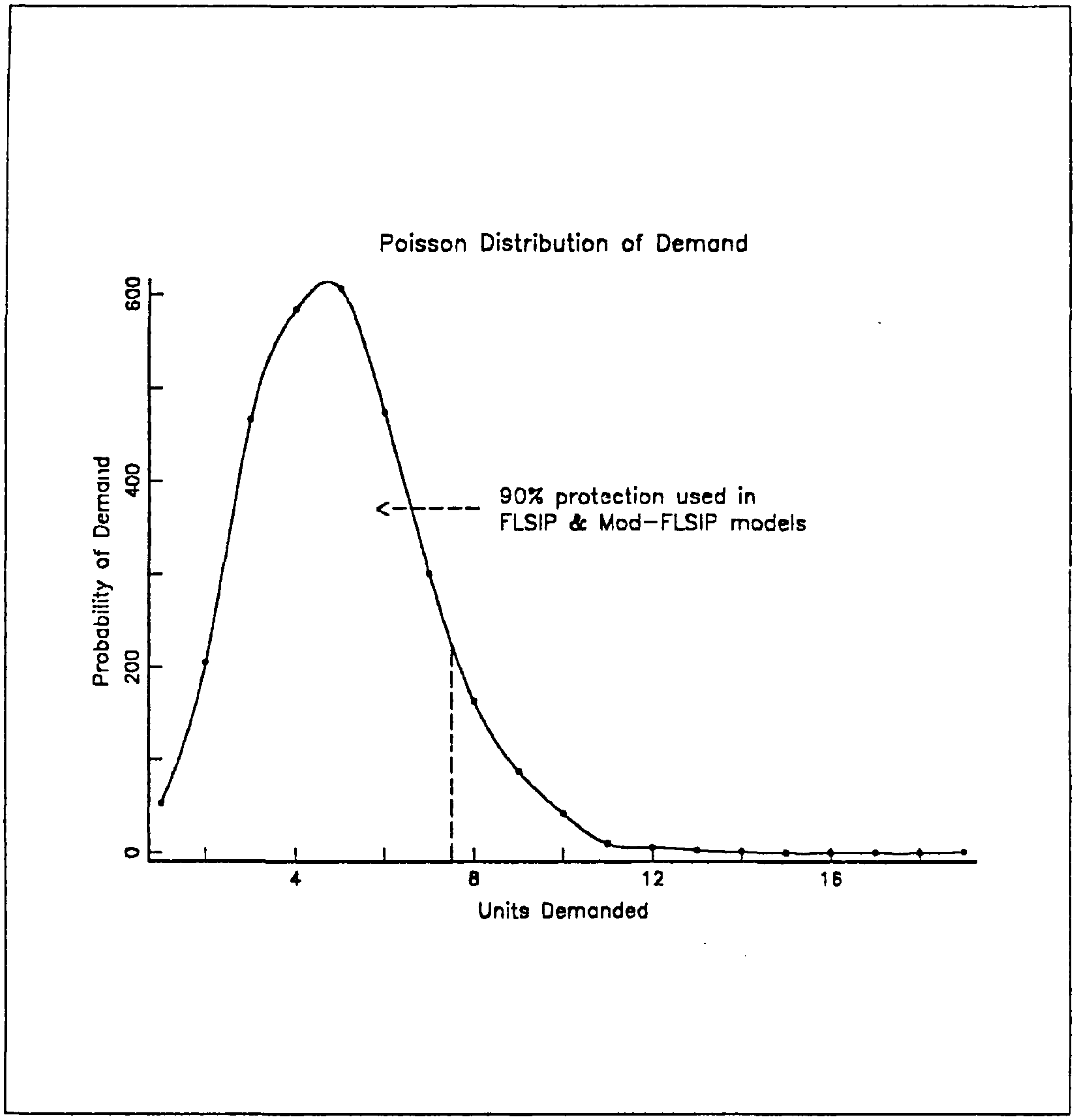

Figure 10. Poisson Distribution of Demand

normal approximation for stockage quantities when the expected annual demand is at least forty units.

The following general rules apply in determining COSAL allowances using the FLSIP and Mod-FLSIP models:

1. FLSIP

- Parts candidates are limited to shipboard installable items. The range of items is determined by those items which have a predicted demand of at least one in four years.

- Levels are determined for an endurance support period of ninety days.

- If a part is expected to be demanded four or more times annually, a fixed level of protection (generally 90%) is set.

- If expected demand is at least forty in a 90 day period, the approximation:

  $$\text{Allowance Qty} = E[AD] / 4 + 1.28 * \sqrt{(E[AD] / 4)}$$

  where, E[AD] (expected annual demand) is used to compute allowance levels.

- Items vital to secondary ship's missions with:

  $$1/4 <= E[AD] < 4$$

  are stocked with a depth of one.

2. MOD-FLSIP

The rules which apply to Mod-FLSIP are the same as above with the following additions:

- Items vital to primary ship's missions with:

$$2 <= E[AD] < 4$$

are stocked with a depth of two.

- Items vital to primary ship's missions with:

$$1/10 <= E[AD] < 2$$

are stocked with a depth of one.

C. ACIM

The ACIM optimization model determines allowance quantities based on obtaining a specific A_o while minimizing cost or maximizing A_o under a given budget constraint. By doing so, it comes closer to the idea of directly connecting supply levels to A_o and mission dependability. As mentioned earlier however, ACIM falls short in that mission availability, the success rate for an entire mission duration, is not reflected in ACIM level computations.

D. COMMENTS

The specifics of the FLSIP, Mod-FLSIP and ACIM model computations are not as important as their relation or non-relation to system availability. Specifically, fixed level protection models and ACIM address neither the idea of achieving a certain level of operational availability given a ship's mission nor the mission success rate or dependability.

APPENDIX D

GPS-5 SYSTEM PARAMETERS

Input Data

* Number of Systems Per Ship - 1
* Number of Operating Hours Per Year - 6000
* Number of Years Simulated - 1
* Mean Time To Repair (MTTR) - 1.5 Hours
* Mean Logistics Delay Time (MLDT) - 17.5 Days
* Duty Cycle - 100 Percent

APPENDIX E

GPS-5 SYSTEM CONFIGURATION

ISN	PART NUMBER	NAME	TRF	SHIP QTY
A195	R-2331/URN	RECEIVER	0.0050	1
A200	646-4237-001	CORRELATOR	0.1610	5
A205	646-4238-001	SYNTHESIZER	0.0946	1
A210	646-4239-001	IF PROCESSOR	0.2052	1
A215	687-6516-001	RCVR PROCESSO	0.4951	1
A220	659-5372-001	LOCAL BUS MEM	0.1726	1
A225	687-7003-001	INTFC PROCESS	0.2135	1
A230	646-4251-001	PTTI INTERFAC	0.1282	1
A235	646-4247-001	INSTR INTERF	0.1811	1
A240	646-4253-001	TEST INTERFAC	0.0613	1
A245	646-4248-001	ARINC INTERF	0.1984	1
A250	646-4252-001	NTDS INTERFAC	0.0981	2
A255	646-4254-001	SYNCHRO INTER	0.0864	1
A260	687-6506-001	CHASSIS	0.0200	1
A265	277-0599-010	OSC XTAL CONT	0.2920	1
A270	687-6510-001	POWER SUPPLY	0.1342	1
A275	BA3042U	BATTERY	0.5000	3 *
A280	C-11702/UR	CONTROL CONSOLE	0.0260	2 **
A285	687-8683-002	CHASSIS	0.0059	2
A290	687-1751-001	DEFLECT/VIDEO	0.0242	2
A295	659-5329-001	PROC/CHAR GEN	0.0841	2
A300	687-8682-001	POWER SUPP	0.0500	2
A305	687-9198-002	ASSY CRT	0.7999	2
A310	687-9162-001	HV POWER SUPP	0.7000	2
A315	687-8819-001	FRONT PANEL ASSY	0.2217	2
A320	754-2000-001	PANEL, KEYBOARD	0.3245	2
A325	MT-6486/SRN	MTG BASE ELEC	0.0050	2
A330	AM-7314/URN	AMPLIFIER ANT	0.0350	1
A350	01-01372-001	ANT FRPA-3	0.1314	1

* Due to the fact that the battery has historically exhibited "wear out" characteristics, it was excluded from the ACIM sparing process and TIGER simulation.

** All items were considered critical for the GPS-5 system to function with the exception of the control console. This item only required one of two for the system to function (i.e., "cold standby spare") [Ref. 14]

APPENDIX F

ACIM STOCK LEVELS FOR GPS-5 SYSTEM

ISN	PART NUMBER	NAME	PRICE	ACIM 95%QTY
A195	R-2331/URN	RECEIVER	59317.00	0
A200	646-4237-001	CORRELATOR	2330.00	3
A205	646-4238-001	SYNTHESIZER	1047.00	1
A210	646-4239-001	IF PROCESSOR	1980.00	2
A215	687-6516-001	RCVR PROCESSO	3763.00	2
A220	659-5372-001	LOCAL BUS MEM	1863.00	2
A225	687-7003-001	INTFC PROCESS	3763.00	2
A230	646-4251-001	PTTI INTERFAC	2375.00	1
A235	646-4247-001	INSTR INTERF	1863.00	2
A240	646-4253-001	TEST INTERFAC	2106.53	1
A245	646-4248-001	ARINC INTERF	1251.00	2
A250	646-4252-001	NTDS INTERFAC	1251.00	2
A255	646-4254-001	SYNCHRO INTER	2379.00	1
A260	687-6506-001	CHASSIS	5135.48	1
A265	277-0599-010	OSC XTAL CONT	1633.00	2
A270	687-6510-001	POWER SUPPLY	2454.97	1
A280	C-11702/UR	CONTROL CONSOLE	8524.00	0
A285	687-8683-002	CHASSIS	5135.48	0
A290	687-1751-001	DEFLECT/VIDEO	391.00	0
A295	659-5329-001	PROC/CHAR GEN	864.59	0
A300	687-8682-001	POWER SUPP	917.00	0
A305	687-9198-002	ASSY CRT	579.77	2
A310	687-9162-001	HV POWER SUPP	414.94	2
A315	687-8819-001	FRONT PANEL ASSY	240.00	1
A320	754-2000-001	PANEL, KEYBOARD	700.00	1
A325	MT-6486/SRN	MTG BASE ELEC	4090.00	0
A330	AM-7314/URN	AMPLIFIER ANT	2701.00	1
A350	01-01372-001	ANT FRPA-3	568.00	2

APPENDIX G

FLSIP AND MOD-FLSIP STOCK LEVELS

ISN	PART NUMBER	NAME	FLSIP	MOD-FLSIP
A195	R-2331/URN	RECEIVER	0	0
A200	646-4237-001	CORRELATOR	1	1
A205	646-4238-001	SYNTHESIZER	0	1
A210	646-4239-001	IF PROCESSOR	1	1
A215	687-6516-001	RCVR PROCESSO	1	1
A220	659-5372-001	LOCAL BUS MEM	1	1
A225	687-7003-001	INTFC PROCESS	1	1
A230	646-4251-001	PTTI INTERFAC	0	1
A235	646-4247-001	INSTR INTERF	1	1
A240	646-4253-001	TEST INTERFAC	0	0
A245	646-4248-001	ARINC INTERF	1	1
A250	646-4252-001	NTDS INTERFAC	1	1
A255	646-4254-001	SYNCHRO INTER	0	1
A260	687-6506-001	CHASSIS	0	0
A265	277-0599-010	OSC XTAL CONT	1	1
A270	687-6510-001	POWER SUPPLY	0	1
A280	C-11702/UR	CONTROL CONSOLE	0	0
A285	687-8683-002	CHASSIS	0	0
A290	687-1751-001	DEFLECT/VIDEO	0	0
A295	659-5329-001	PROC/CHAR GEN	0	1
A300	687-8682-001	POWER SUPP	1	1
A305	687-9198-002	ASSY CRT	1	2
A310	687-9162-001	HV POWER SUPP	1	2
A315	687-8819-001	FRONT PANEL ASSY	1	1
A320	754-2000-001	PANEL, KEYBOARD	0	1
A325	MT-6486/SRN	MTG BASE ELEC	0	0
A330	AM-7314/URN	AMPLIFIER ANT	0	0
A350	01-01372-001	ANT FRPA-3	0	1

APPENDIX H

ACIM STOCK LEVEL ADJUSTMENTS (PHASE 1)

RULE 1:

ISN	PART NUMBER	NAME	INITIAL QTY	MODIFIED QTY
A305	687-9198-002	ASSY CRT	2	3
A310	687-9162-001	HV POWER SUPP	2	3
A295	659-5329-001	PROC/CHAR GEN	0	1

RULE 2:

ISN	PART NUMBER	NAME	INITIAL QTY	MODIFIED QTY
A260	687-6506-001	CHASSIS	1	0
A240	646-4253-001	TEST INTERFAC	1	0
A330	AM-7314/URN	AMPLIFIER ANT	1	0
A205	646-4238-001	SYNTHESIZER	1	0
A350	01-01372-001	ANT FRPA-3	2	0

Note: The components are listed in the order that they were added or deleted from the initial sparing suite.

APPENDIX I

ACIM STOCK LEVEL ADJUSTMENTS (PHASE 2)

ISN	PART NUMBER	NAME	ACIM	ACIM MODIFIED
A195	R-2331/URN	RECEIVER	0	0
A200	646-4237-001	CORRELATOR	3	1
A205	646-4238-001	SYNTHESIZER	1	0
A210	646-4239-001	IF PROCESSOR	2	1
A215	687-6516-001	RCVR PROCESSO	2	1
A220	659-5372-001	LOCAL BUS MEM	2	1
A225	687-7003-001	INTFC PROCESS	2	1
A230	646-4251-001	PTTI INTERFAC	1	1
A235	646-4247-001	INSTR INTERF	2	1
A240	646-4253-001	TEST INTERFAC	1	0
A245	646-4248-001	ARINC INTERF	2	1
A250	646-4252-001	NTDS INTERFAC	2	1
A255	646-4254-001	SYNCHRO INTER	1	1
A260	687-6506-001	CHASSIS	1	0
A265	277-0599-010	OSC XTAL CONT	2	1
A270	687-6510-001	POWER SUPPLY	1	1
A280	C-11702/UR	CONTROL CONSOLE	0	0
A285	687-8683-002	CHASSIS	0	0
A290	687-1751-001	DEFLECT/VIDEO	0	0
A295	659-5329-001	PROC/CHAR GEN	0	0
A300	687-8682-001	POWER SUPP	0	0
A305	687-9198-002	ASSY CRT	2	2
A310	687-9162-001	HV POWER SUPP	2	2
A315	687-8819-001	FRONT PANEL ASSY	1	1
A320	754-2000-001	PANEL, KEYBOARD	1	1
A325	MT-6486/SRN	MTG BASE ELEC	0	0
A330	AM-7314/URN	AMPLIFIER ANT	1	0
A350	01-01372-001	ANT FRPA-3	2	0

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